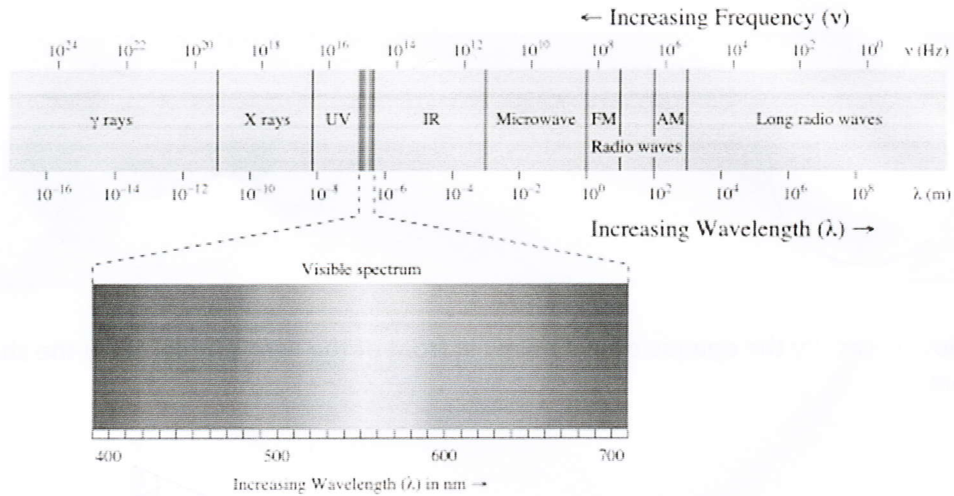
Unit III - Reflection of Light

Introduction to Light

The **electromagnetic spectrum** is the range of wavelengths that light can exist in.

An electromagnetic wave is simply a light wave. However, we reserve the term **light** for the part of the spectrum we can see. This is called the **visible** part of the spectrum. Other parts of the spectrum have different names. It is important to note that each type of wave is a light wave, but just has a different wavelength, energy, and behaviours/purposes.



A **luminous body** is an object that emits light.
Ex. The sun or other stars, lamps, lightning bugs

A **nonluminous body** does not emit light, but reflects, or absorbs it. These are often referred to as **illuminated bodies**.
Ex. the moon, bricks, almost everything you see

An **incandescent body** is an object that emits light when it is heated. The type, or color, of light it emits depends on its temperature.
Ex. light bulbs, melted metals, candle flame

Light naturally travels in straight lines. This is called **rectilinear propagation**. The only time that light does not travel in a straight line is when it passes through a strong gravitational field.

A **transparent** object transmits light, while it absorbs or reflects some as well.
Ex. ~~glass, air, some liq~~ glass, air, some liquids

A **translucent** object only scatters and transmits light, but does not allow objects to be clearly seen through them.
Ex. tissue paper, frosted glass,

An **opaque** object is neither translucent nor transparent. These objects either absorb or reflect specific wavelengths of light. Most objects are opaque.

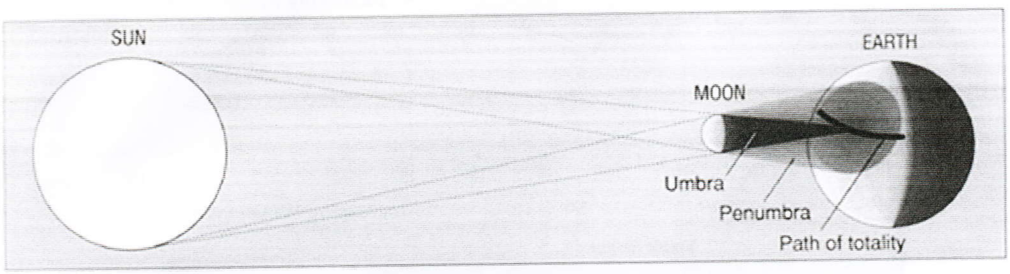
Ex. Bricks, drywall, people

We can represent the path followed by light on paper by drawing **rays**. Rays do not actually exist in nature, but they are geometric constructs that help describe the nature of light.

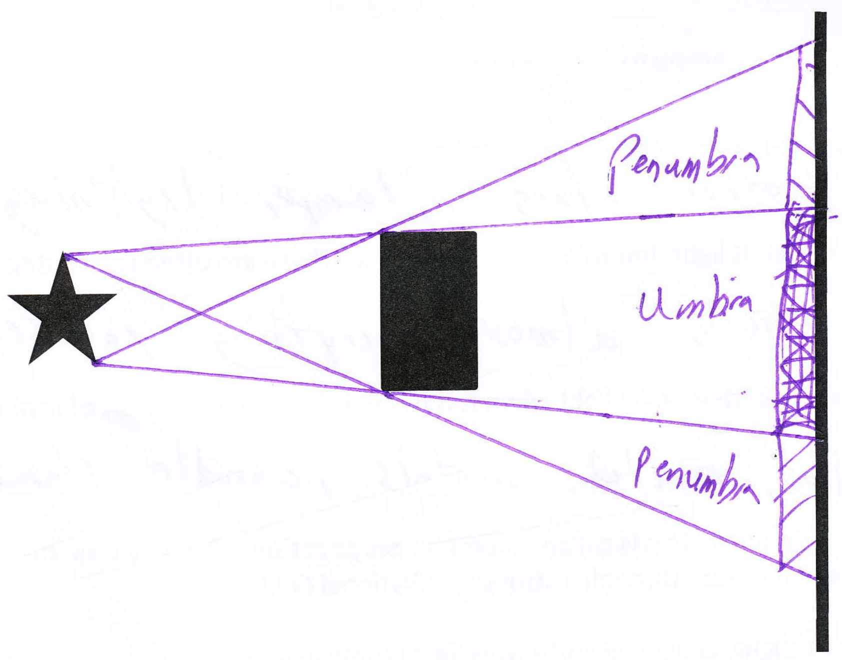
A **beam** is thought of as a collection of rays.

Shadows form when an opaque object is placed in the path of light. We call a total shadow an **umbra**. We call a partial shadow a **penumbra**.

A total solar eclipse is observed from the **umbra** of the moon.



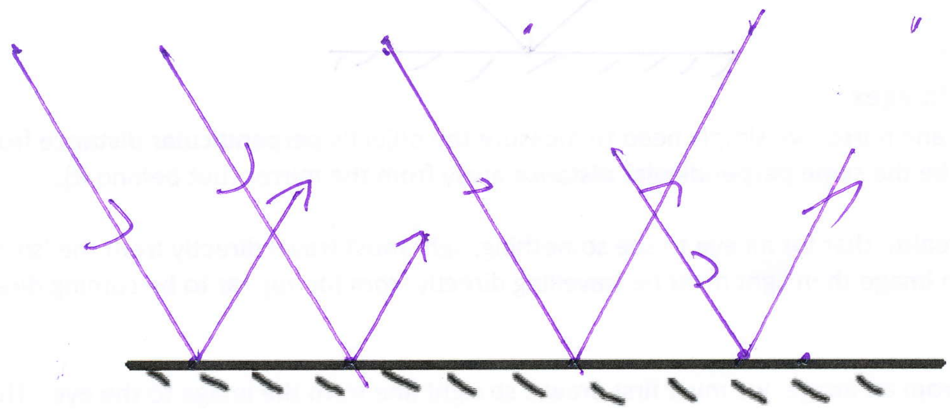
Ex. Draw the shadow(s) cast by the opaque object below in front of the light source. Label the shadow(s) as umbra or penumbra.



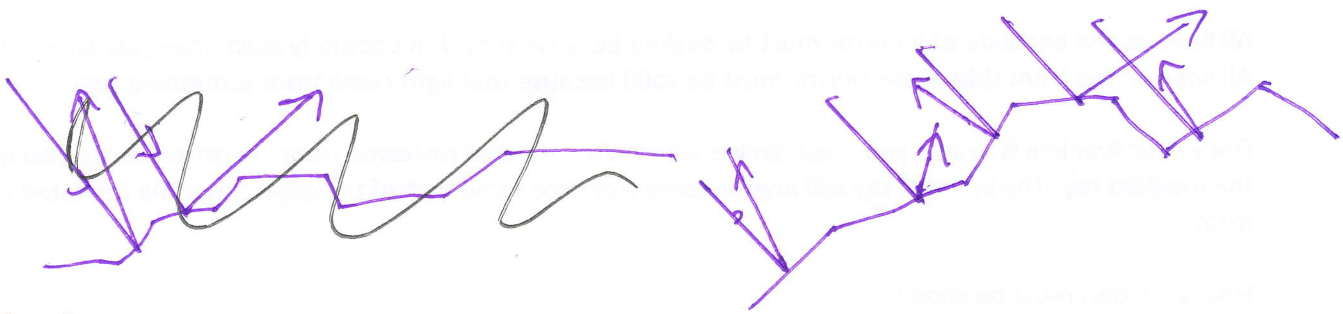
The Law of Reflection and Plane Mirrors

The law of reflection: the angle of reflection is equal to the angle of incidence.

Regular reflection (which occurs in mirrors) is when all the rays in a beam of light are reflected at the same angle.
Ex.



Diffuse reflection (which is much more common) occurs when the rays in a beam of light are scattered off a surface.
Ex.



Describing Images

A plane mirror is a flat mirror.

The images formed in a plane mirror appear to be behind the mirror. This means that the light **appears** to be coming from behind the mirror. We call images formed in this fashion **virtual images**. A virtual image is an image that light does **not** pass through, but only **appears** to pass through.

We describe images with four characteristics:

1) Magnification - is the image smaller or larger than the object?

2) Orientation - is the image upside down or right side up compared to the object?

3) Type - is the image real or virtual? (we will discuss real images later).

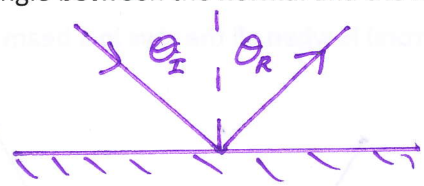
4) Position - is the image closer, further, or the same distance from the mirror as the object?

We locate objects using ray diagrams, which are close approximation to numerical solutions. We will later do the math to get theoretical solutions.

When drawing rays, we must always draw a normal so we can measure the angle of incidence or reflection, and arrows to show which way the rays are traveling.

Recall that the angle of incidence is the angle between the **normal** and the incident ray, **not the mirror!**

Likewise, the angle of reflection is the angle between the **normal** and the reflected ray, **not the mirror!**
Ex.



Locating and Seeing Images

To locate images in a plane mirror we simply need to measure the object's **perpendicular distance** from the mirror. The image will be the same **perpendicular distance** away from the mirror (but behind it).

It is very important to realize that for an eye to see something, light must travel directly from the 'something'. So, if an eye is to see an **image** then light must be travelling directly from (or appear to be coming directly from) the image.

To draw the light rays from an image, we must first draw a straight line from the image to the eye. This ray will turn out to be the **reflected ray**.

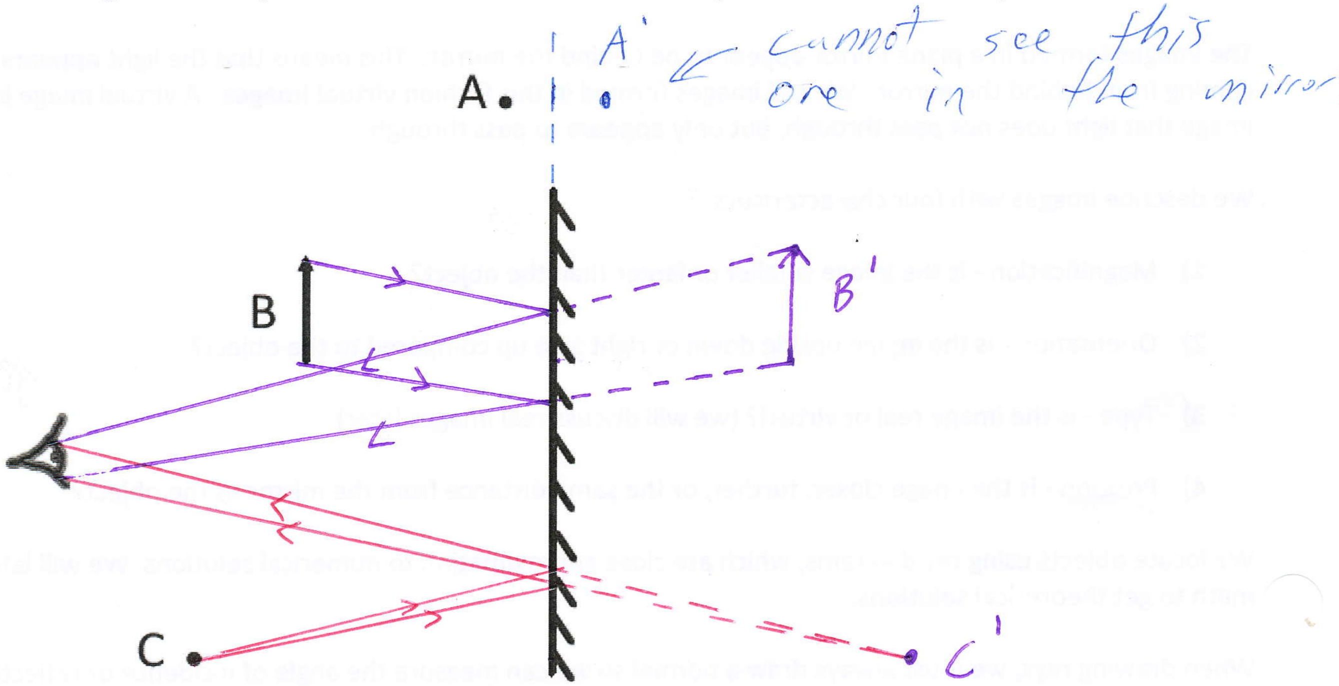
If this straight line does not go through the mirror than the eye cannot see the image!

All lines on the backside of a mirror must be dashed because they don't **actually** exist, they just appear to exist. All lines on the front side of the mirror must be solid because that light came from something real.

Once your first line is drawn you must decide where the reflected ray came from. In other words, you must find the **incident ray**. The incident ray will always come from the same part of the object that the reflected ray came from.

Finally, arrows must be shown.

Ex. Locate the images of the objects below in the mirror. Draw the rays to determine if the eye can see the images.



Curved Mirrors

Although we mostly associate mirrors with plane mirrors, curved mirrors are very useful. Even though their surfaces are curved, curved mirrors still are governed by the law of reflection.

That is, a curved mirror can be thought of several tiny plane mirrors put together at slightly different angles.
Ex.

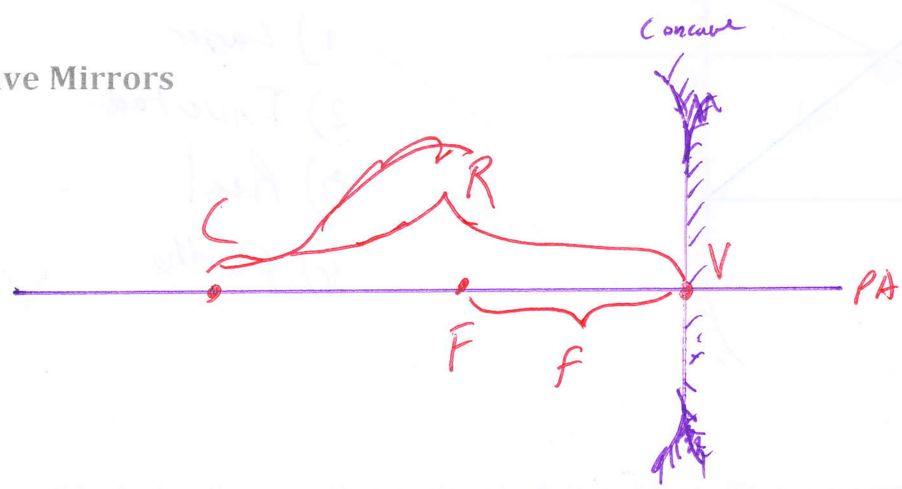
There are two types of curved mirrors we will focus on.

1) **Concave mirrors**: If we imagined a sphere with a shiny inside, and we took a section of this sphere we would have a concave mirror. These are also called **converging** mirrors.

2) **Convex mirrors**: These mirrors are thought of a section of a sphere with a shiny outside. These are also called **diverging** mirrors.

Where have you seen curved mirrors used before?

Concave Mirrors



Definitions:

Vertex (V)- the geometrical center of a curved mirror.

Center of Curvature (C) - the geometrical center of the sphere the mirror is made from.

Principal Axis - a line that passes through the center of curvature and the vertex.

Radius of Curvature (R) - the distance from the center of curvature to the vertex.

Focal Point (F)- a point on the principal axis half way between the center of curvature and the vertex. This is a real point on a concave mirror, and a virtual point on a convex mirror.

Focal Length (f)- distance between focal point and the vertex. note: $R = 2f$

The Principal Rays

There are three rays we will use to locate images in curved mirrors. These are called principal rays.

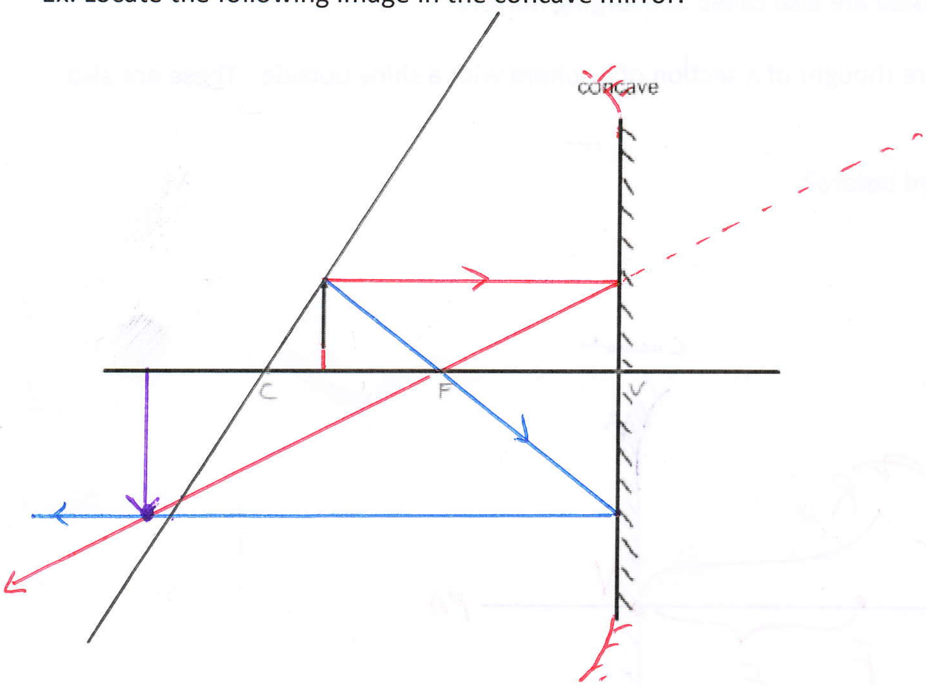
1) A ray travelling parallel to the principal axis will reflect through the focal point.

2) A ray travelling through the focal point will reflect parallel to the principal axis.

3) A ray that appears to travel through, or come from the center of curvature, will be reflected back in the direction it came from.

To locate an image, we need only 2 of the principal rays. However, if you draw accurately, all 3 rays should pass through the same point on an image.

Ex. Locate the following image in the concave mirror:



Description of Image

1) Larger
2) Inverted
3) Real
4) Farther

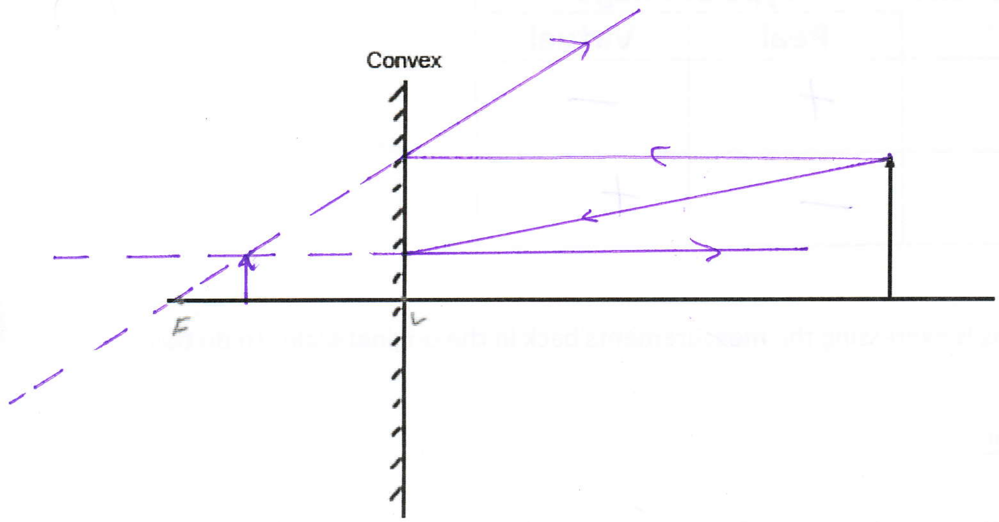
Convex Mirrors

To locate images in convex mirrors we can still use the same 3 principle rays. However, they look a bit differently in this type of mirror.

For a convex mirror, the focal point is behind the mirror, so this is a virtual point. If the focal point is virtual, then light actually does not go through it, light just appears as if it does.

Furthermore, for a convex mirror, all the images will be upright, virtual, and smaller than the object. The images will also appear between the focal point and the vertex.

Ex) Locate the image of the following object in the mirror below.



Scale Diagrams

We now know that locating images for objects that are about 2-3 cm in height is easy to do on paper. However, this is not very practical. For example, how are we supposed to locate the image of a person in a curved mirror if our paper is too small?

The answer is in scale diagrams!

A scale diagram is when you take measurements that are normally too big to fit on paper and shrink them down to a manageable size. Once the numbers are more manageable, we can draw ray diagrams to locate the images of large objects, and then use our scale to find out how big they would be in real life.

We are going to start defining a few measurements to make our lives easier from this point on:

The **distance of the object (d_o)** is the distance between the object and the mirror. We say that this is **always** a positive number as it is measured in front of the mirror.

The **distance of the image (d_i)** is the distance between the image and the mirror. If the image is **real** this will be a positive number. If the image is **virtual** (behind the mirror) this will be a negative number.

The **height of the object** is denoted h_o. This will be a positive number since our objects are always right side up.

The **height of the image** is denoted h_i. If the image is real, then the image is inverted; therefore, h_i will be negative. If the image is virtual, then the image is right side up; therefore hi will be positive.

Here is a chart to summarize the sign conventions discussed:

Measurement	Type of Image	
	Real	Virtual
d_i	+	−
h_i	−	+

One of the trickiest parts of scale diagrams is expressing the measurements back in the original scale. To do this, we can use proportions.

A handy proportion is $\frac{real\ life\ measurement}{scale\ measurement}$.

Ex. A diagram drawn to scale shows the distance of an image from a mirror is 2.50 cm. If the scale of the ray diagram is 1 m = 1 cm, how many meters is the image actually from the mirror?

$\frac{real}{scale} = \frac{1m}{1cm} = \frac{x}{2.50cm}$ $\quad \frac{2.50\ \cancel{cm}\ m}{1\ \cancel{cm}} = \frac{x\ 1cm}{1cm}$ $\quad \boxed{x = 2.50\ m}$

Ex. A diagram drawn to scale shows the height of an image is 3.30 cm. If the scale of the ray diagram is 3 m = 2 cm, how tall is the actual image?

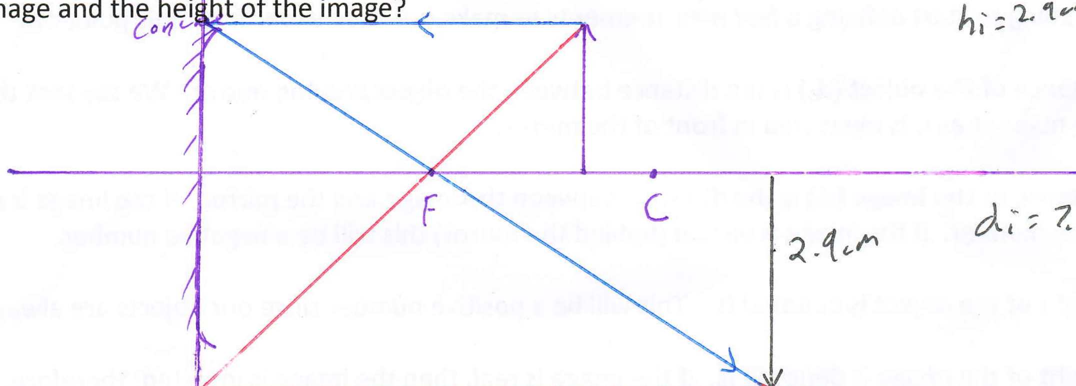
$\frac{3m}{2cm} = \frac{x}{3.30cm}$ $\quad \frac{9.90\ \cancel{cm}\ m}{2\ \cancel{cm}} = \frac{x(2\ cm)}{2cm}$ $\quad \boxed{4.95\ m = x}$

The scale you are drawing your diagram to must always be stated somewhere. This is usually done in the top left hand corner so that it is seen first.

Ex. A 2.00 m tall man is standing 5.00 m from a concave mirror with a focal length of 3.00 m. What is the distance of the image and the height of the image?

1 cm = 1m

$h_i = 2.9cm = \boxed{2.9m}$

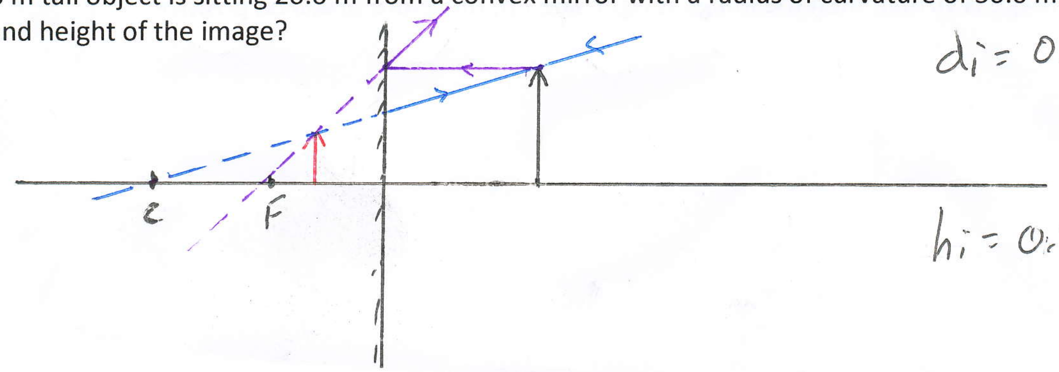


$d_i = 7.5cm = \boxed{7.5m}$

Ex. A 15.0 m tall object is sitting 20.0 m from a convex mirror with a radius of curvature of 30.0 m. What is the distance and height of the image?

1cm = 10m

$d_i = 0.9cm = \boxed{9m}$



$h_i = 0.7cm = \boxed{7m}$

Curved Mirror Mathematics

Now that we know how to locate images visually, let's see how we can locate and describe images mathematically. We will use two equations to describe images mathematically. The first equation is known as the **mirror equation**.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where:

- f = focal length
- do = distance of the object
- di = distance of the image

Recall that sometimes the distance or height of our image is positive, but sometimes it is negative. You may need to refer to the chart below for mirror math questions:

	Positive	Negative
d_o	Always	Never
h_o	Always	Never
d_i	Real	Virtual
h_i	Upright	Inverted
f	Concave (converging)	Convex (Diverging)

Ex. A 3.0 cm tall object is 6.0 cm from a concave mirror. If the image produced is 5.0 cm from the mirror, what is the focal length?

$h_o = 3.0\,cm$
$d_o = 6.0\,cm$
$d_i = +5.0\,cm$
$f = ?$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{f} = \frac{1}{6.0cm} + \frac{1}{+5.0cm}$

$\frac{1}{f} = +\frac{11}{30\,cm}$

$\left(\frac{1}{f}\right)^{-1} = \left(+\frac{11}{30\,cm}\right)^{-1}$

$f = \frac{30\,cm}{11}$

$\boxed{f = 2.7\,cm}$

We can also describe the size of the image by calculating its magnification (M). The following equations are known as the **magnification relationships**:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Ex. A 2.7 m tall object produces a real image 1.1 m tall. What is the magnification?

$h_o = 2.7m$
$h_i = -1.1m$

$M = \frac{h_i}{h_o}$ $\quad M = \frac{-1.1m}{2.7m}$ $\quad \boxed{M = -0.41}$

Ex. An object produces a virtual image 2.5 m away from a concave mirror. If the focal length is 3.0 m, what is the distance of the object from the mirror?

$d_i = -2.5m$
$f = 3.0m$
$d_o = ?$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{3.0m} = \frac{1}{d_o} + \frac{1}{-2.5}$

$\frac{1}{3.0m} = \frac{1}{d_o} - \frac{1}{2.5m}$

$\frac{1}{3.0m} + \frac{1}{2.5}m = \frac{1}{d_o}$

$\left(\frac{11}{15m}\right)^{-1} = \left(\frac{1}{d_o}\right)^{-1}$

$\frac{15m}{11} = d_o$

$\boxed{d_o = 1.4m}$

Many questions need a combination of the mirror equation and one of the magnification relationships if there are too many unknowns.

Ex) A 2.0 m tall object 1.6 m in front of a convex mirror produces an image 0.625 m tall. What is the focal length of the mirror?

$h_o = 2.0m$

$d_o = 1.6m$

$h_i = \cancel{+}0.625m$

$f = ?$

$d_i = ?$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$M = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{-0.625m}{2.0m} = \frac{-d_i}{1.6m}$

$\frac{1.0m^2}{2.0m} = -d_i$

$\boxed{\cancel{+}-0.50m = d_i}$

$\cancel{\frac{1}{f} = \frac{1}{1.6m} + \frac{1}{+0.50m}}$

$\cancel{\left(\frac{1}{f}\right) = \left(\frac{21}{8}\right)^{-1}}$

$\cancel{f = \frac{8}{21}}$

$\cancel{\boxed{f = 0.38m}}$

Fix

$\frac{1}{f} = \frac{1}{1.6m} + \frac{1}{-0.50m}$

$\left(\frac{1}{f}\right)^{-1} = \left(\frac{-11}{8m}\right)^{-1}$

$f = \frac{-8m}{11}$

$\boxed{f = -0.73m}$